

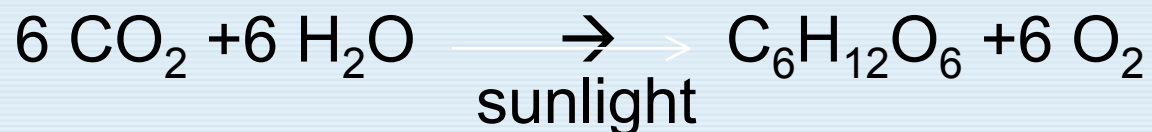
# Biomass to Hydrogen

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# Biomass Feedstocks



Potential : 15% of the world's energy by 2050.

Fischer and Schrattenholzer, *Biomass and Bioenergy* 20 (2001) 151-159.

## Crop residues

Forest residues

Energy crops

Animal waste

Municipal waste

*Issues: Availability and Costs*

## ■ Potential

- H<sub>2</sub>: the Inevitable Energy Carrier of the Future
- Biomass is Renewable
- Zero Net CO<sub>2</sub> Impact
- Potential for Near Term Renewable H<sub>2</sub> Deploym

## ■ Challenges

- No Completed Technology Demonstrations
- Low Yield of H<sub>2</sub>
- Not yet competitive with Natural Gas Steam Reforming
- Requires Appropriate H<sub>2</sub> Storage and Utilization Scenarios

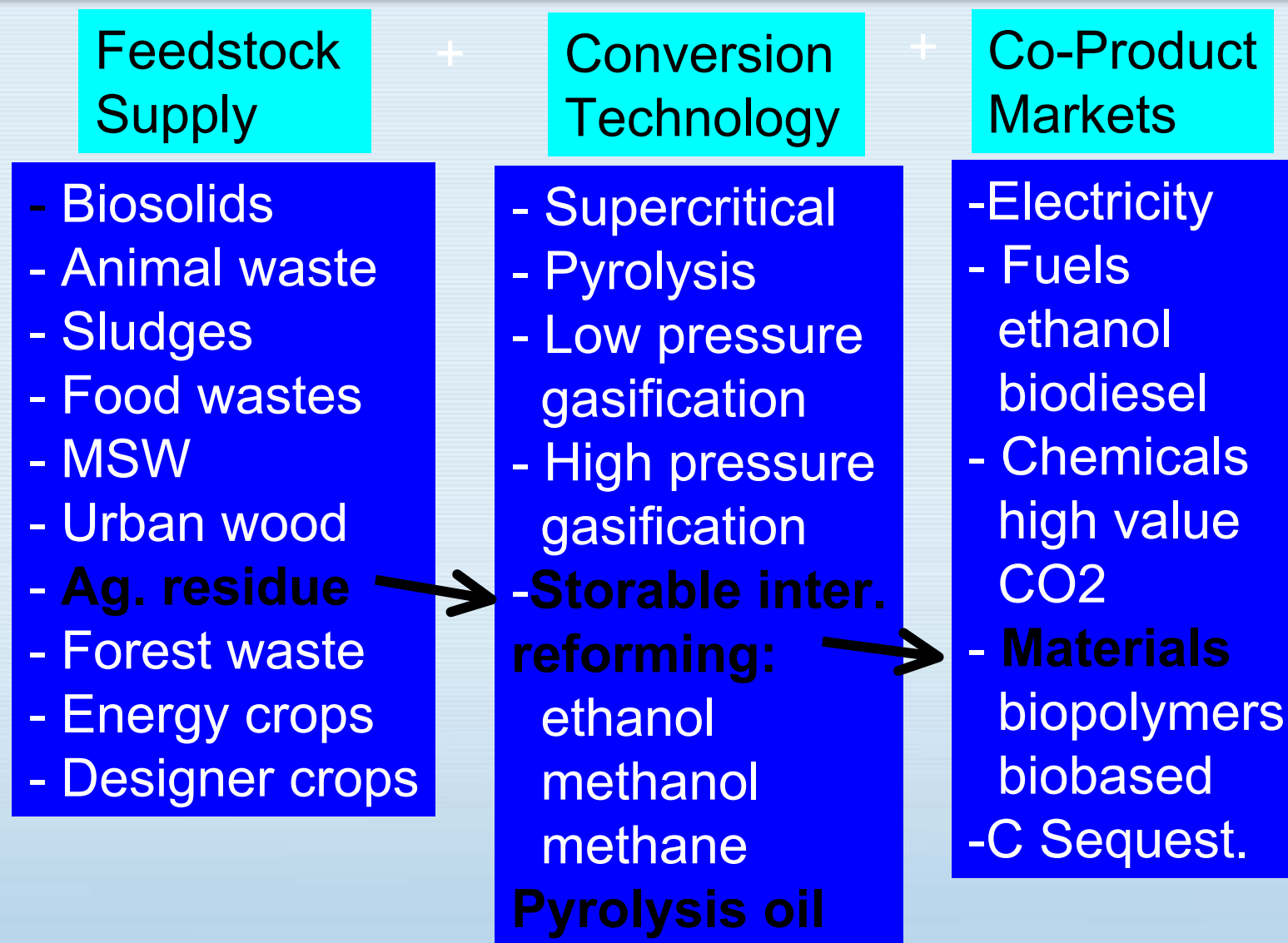


# Potential Impact

- Bioenergy
  - Supply 15% of the world energy by 2050 150 EJ
  - Economic Renewable H<sub>2</sub> in the Near Term
  - Deployment in Developing Energy Markets
  - The Biomass Refinery: Co-product Economics
- Hydrogen As the Energy Carrier
  - Flexibility: Biological and Thermal Routes
  - CHP
  - High Efficiency Conversion
  - Environmental Benefits
  - Allows Integration with other Renewable Technologies



# Biomass -> H<sub>2</sub> Integration



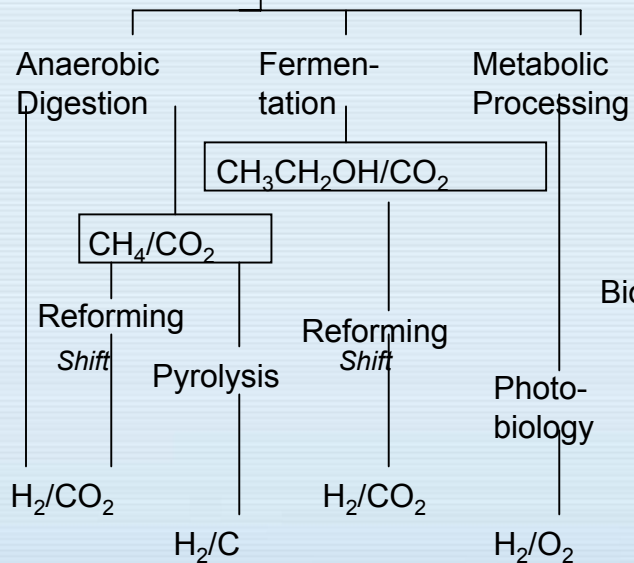


# Possible Development Scenario

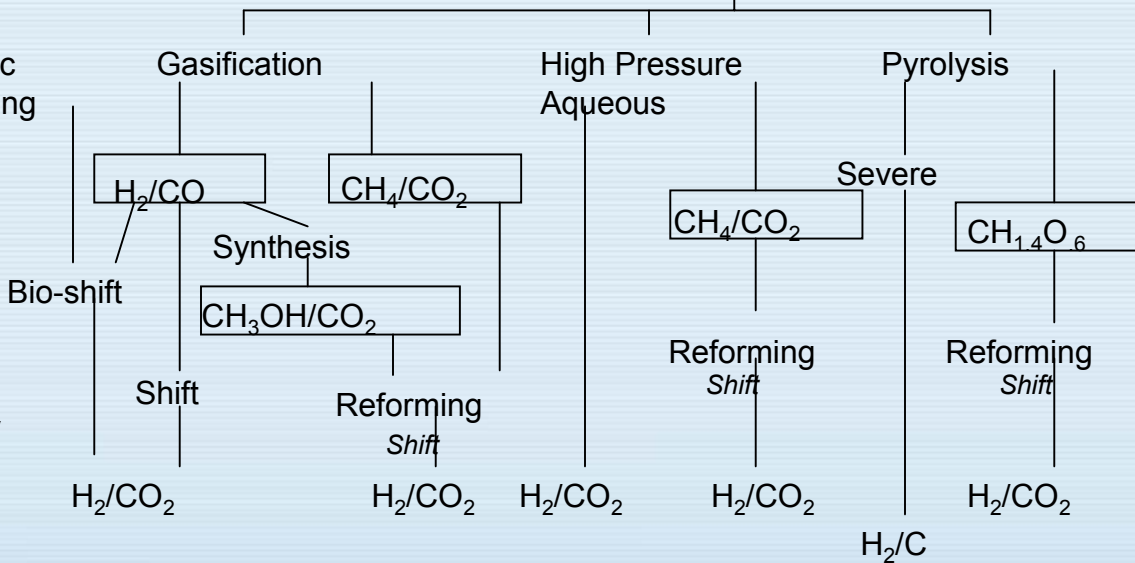
	Near Term	Mid Term	Long Term
<b>Biomass</b>	Resid. Biomass Pyrolysis/ SR Coproducts Cofeed NG	+ Energy Crops + Gasification + C Sequest. + Adv. Coal	+ Biomass Refineries
<b>Hydrogen</b>	On-Site Prod Hythane NG, Electrol.	+ Storage + Dist. Gen. + Fuel Cells	+ Hydrogen Economy

# BioResource

## Biological



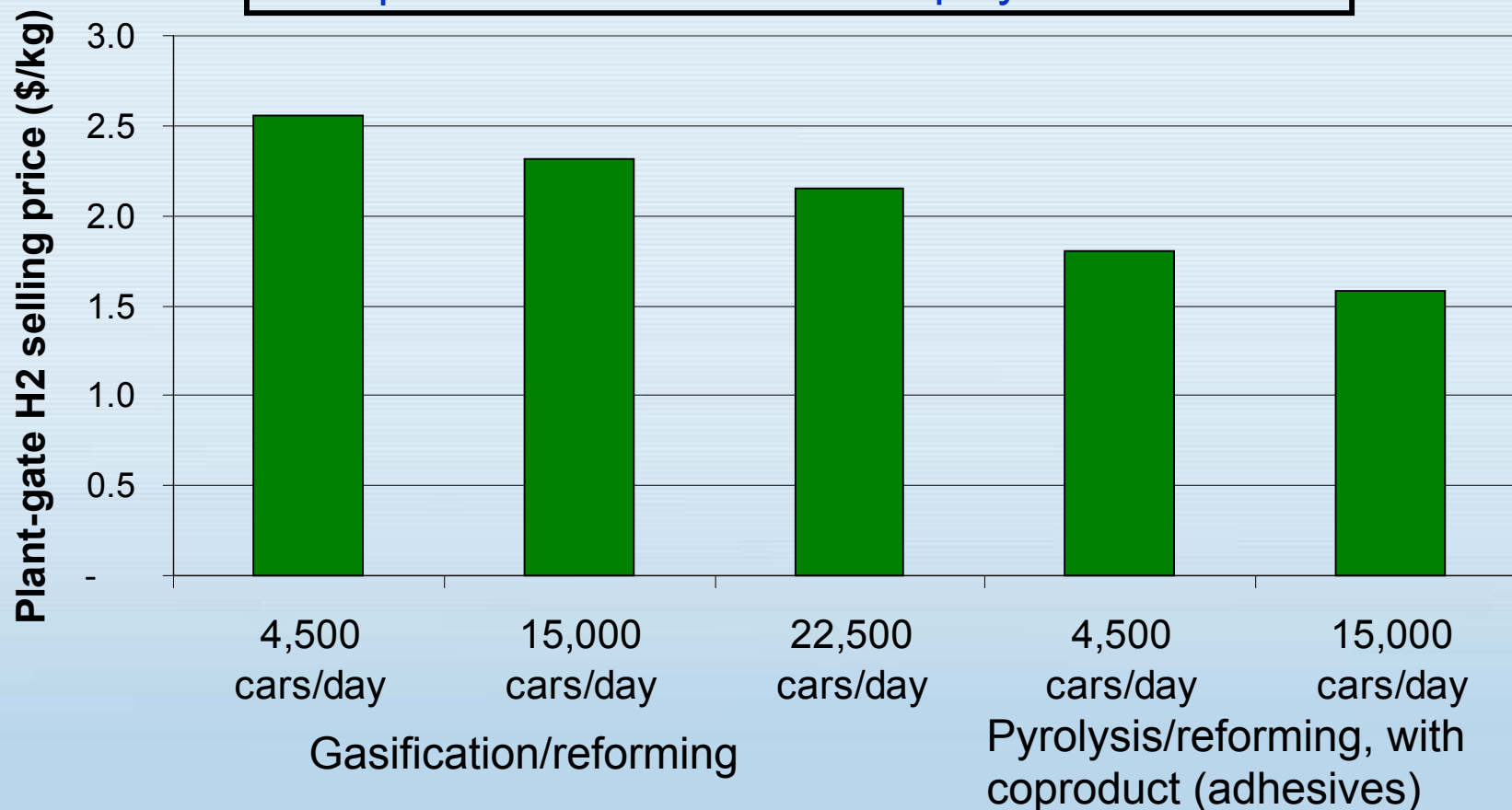
## Thermochemical



# Economics

## Major assumptions:

- 15% after-tax IRR
- 20 year plant life
- $n^{\text{th}}$  plant
- MACRS depreciation
- 90% capacity factor
- Equity financed

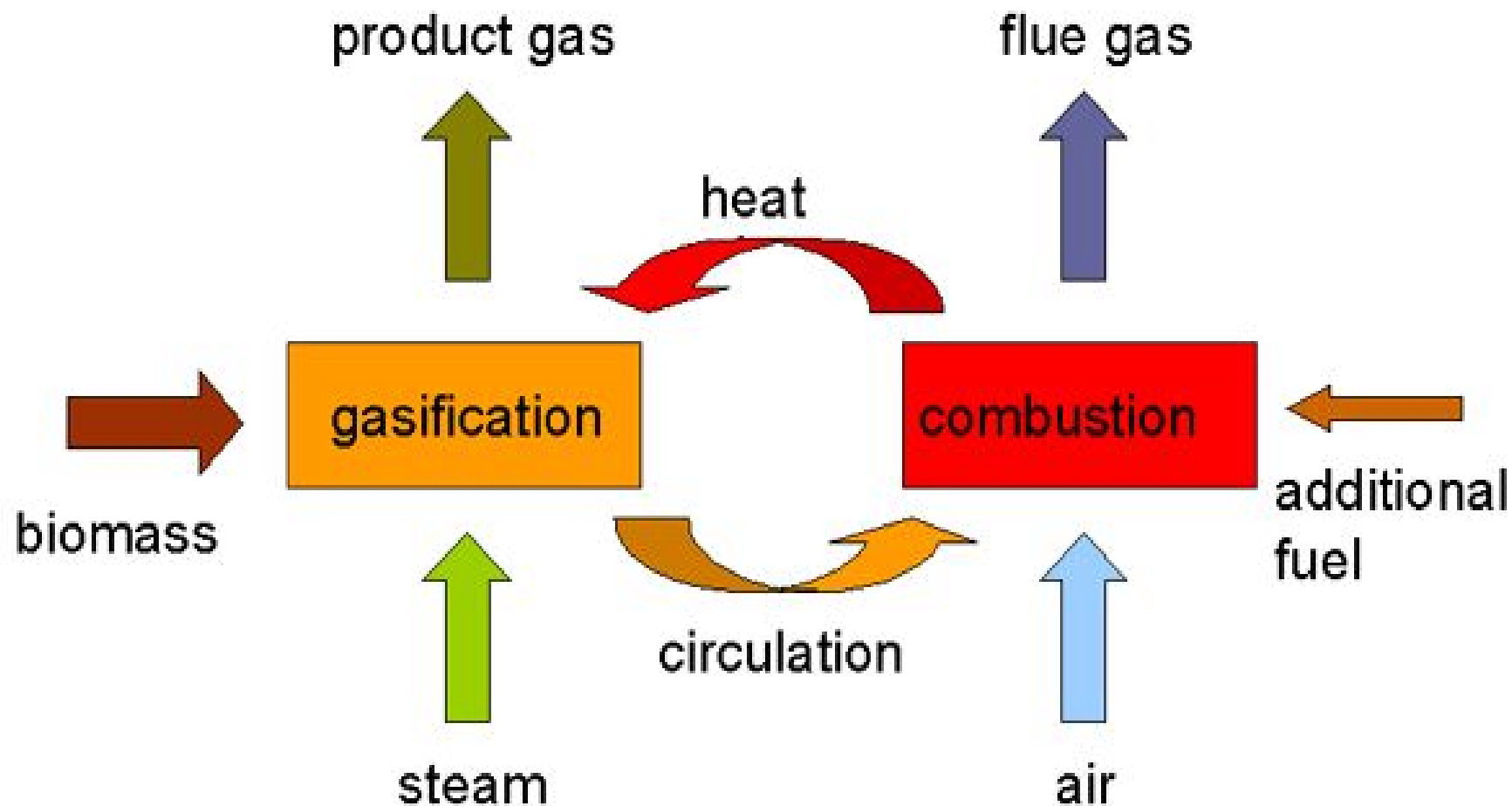




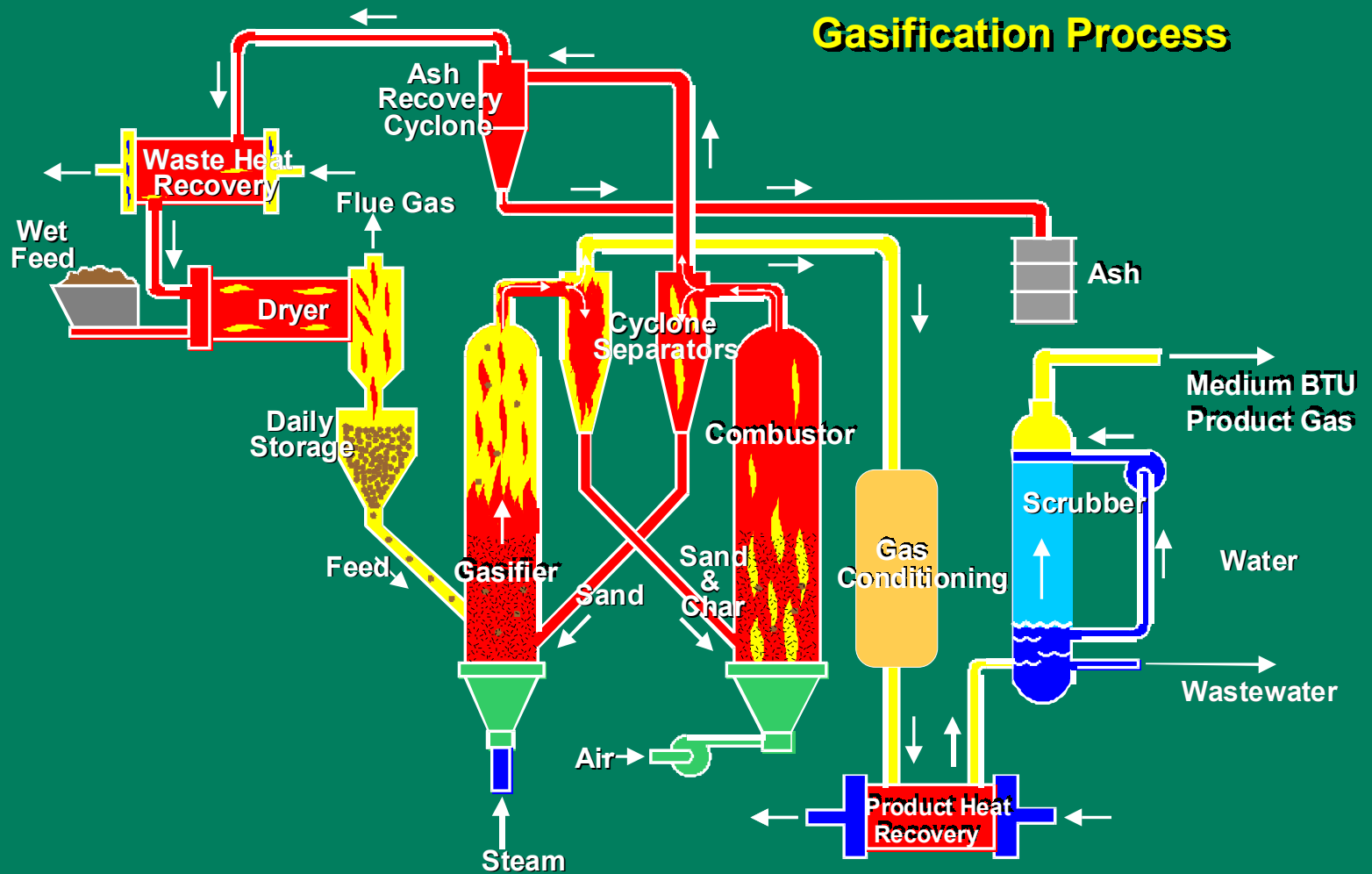
# Biomass Gasification



# Multi-Stage Gasification



## The FERCO SilvaGas Biomass Gasification Process



# TPS Termiska Processor (SE)



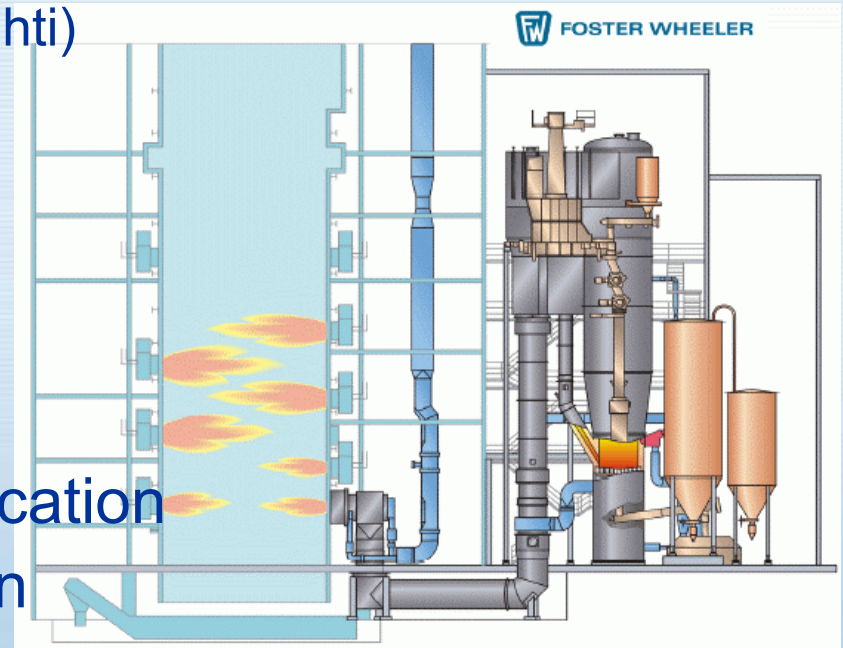
- Feedstock variety
  - variety of biomass / waste feedstocks, RDF
- Scale
  - 18 MWth test facility Värnamo (SE)
  - 2.5 MWth pilot in Studsvik (SE)
  - industrial units
    - ARBRE (UK): 25 MWth (40 000 t/a energy crops)
    - Greve in Chianti (IT): 2\*18 MWth (200 t/d pelletised RDF)
- Technology
  - pressurised CFB gasification
  - hot gas conditioning



# VTT Processes (FI)



- Feedstock variety
  - biomass / waste
- Scale
  - gasification
    - CFB: 60 MWth  
19 t/h wood + waste (Lahti)
    - fixed bed:  
0.5 MWth (new pilot)
- Technology
  - CFB gasification
  - fluid bed gasification
  - fixed bed updraft gasification
  - biomass fuel production



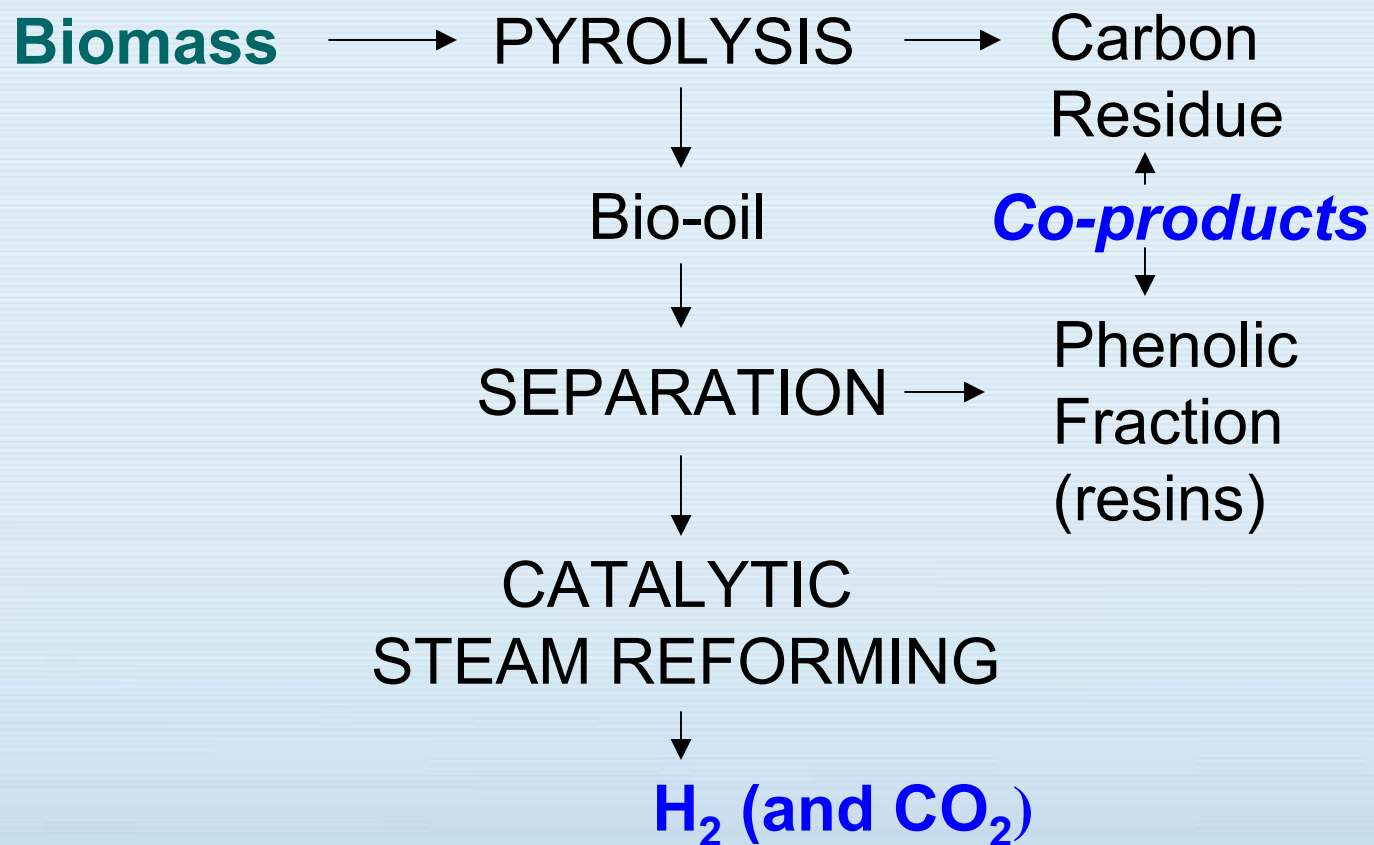


# Research, Development and Deployment Challenges

- Feedstock preparation
- Gasification: gas conditioning
- Pyrolysis: co-product development
- Modular systems
- System integration
- Bio-oil reforming demonstration
- Wet Biomass Demonstration

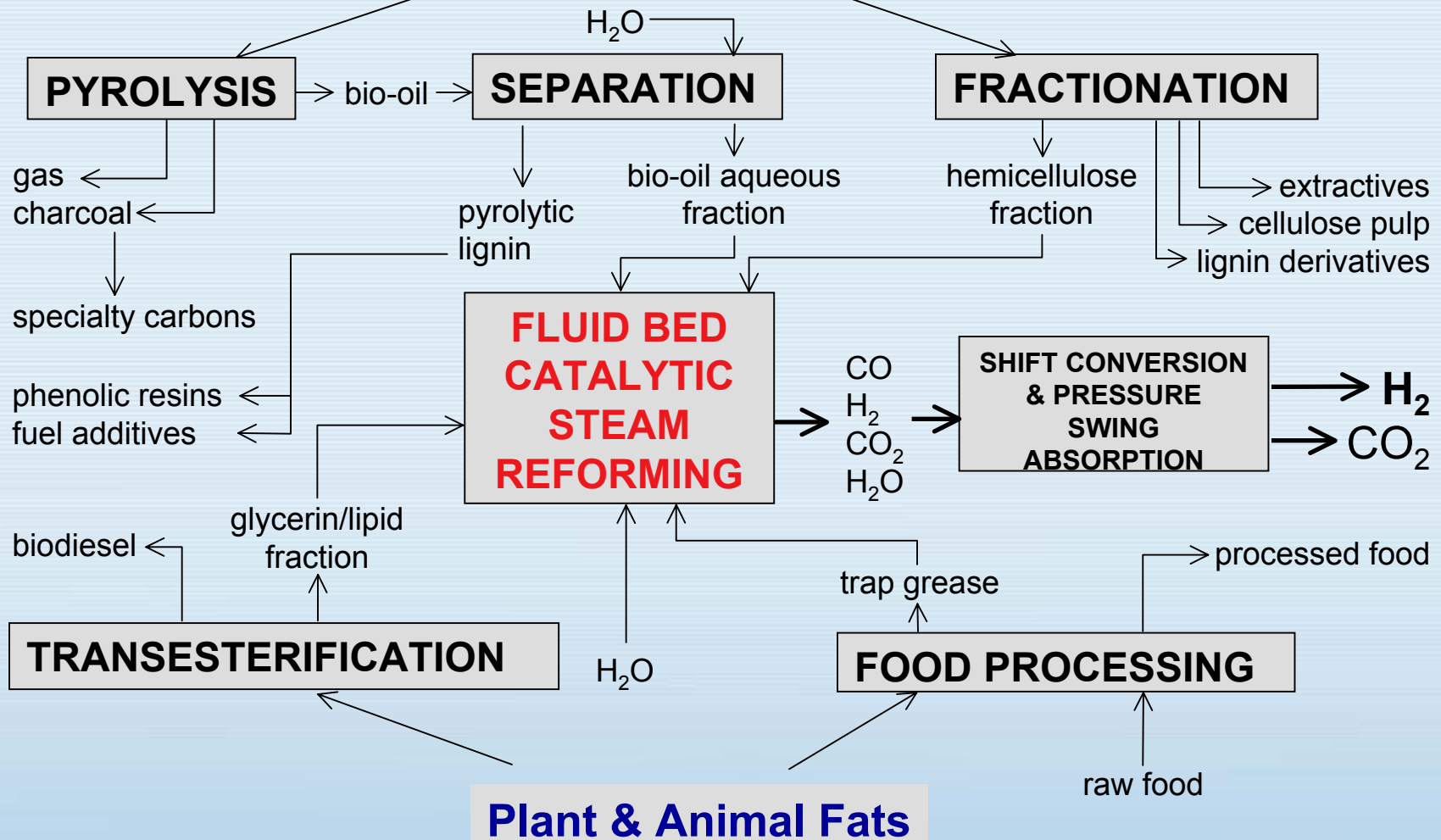


# Pyrolysis Process Concept





## Lignocellulosic Biomass

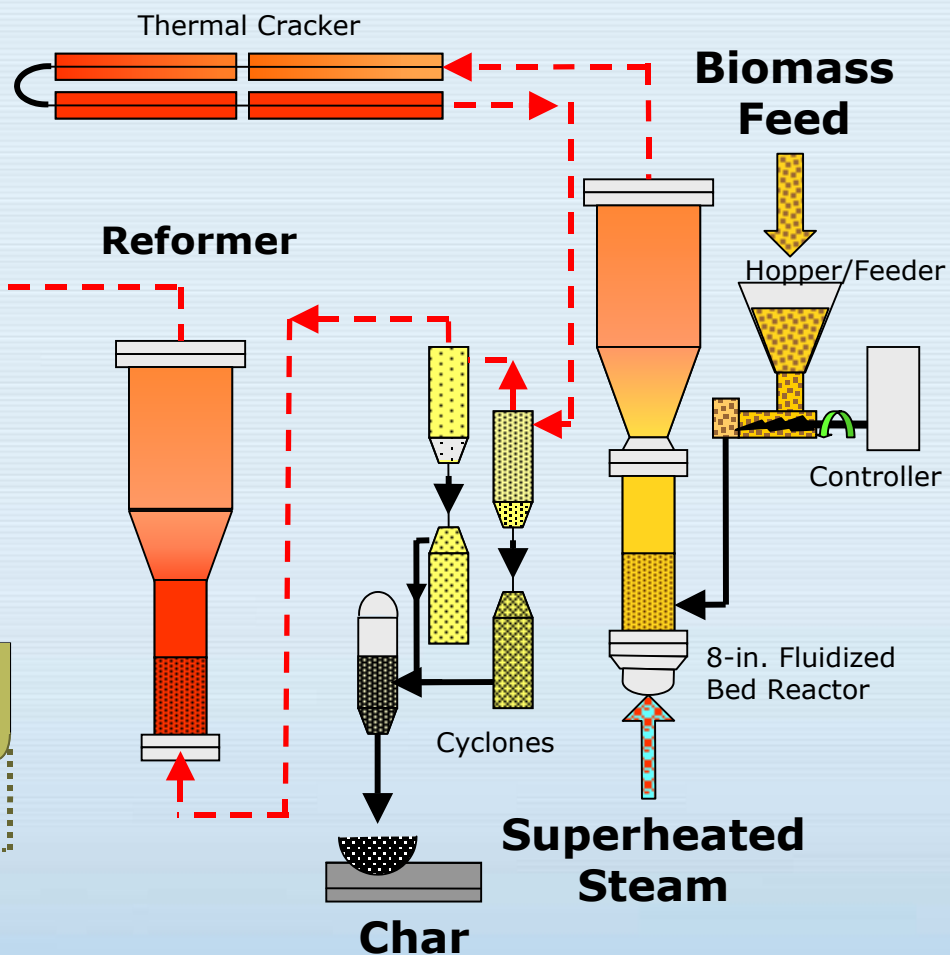
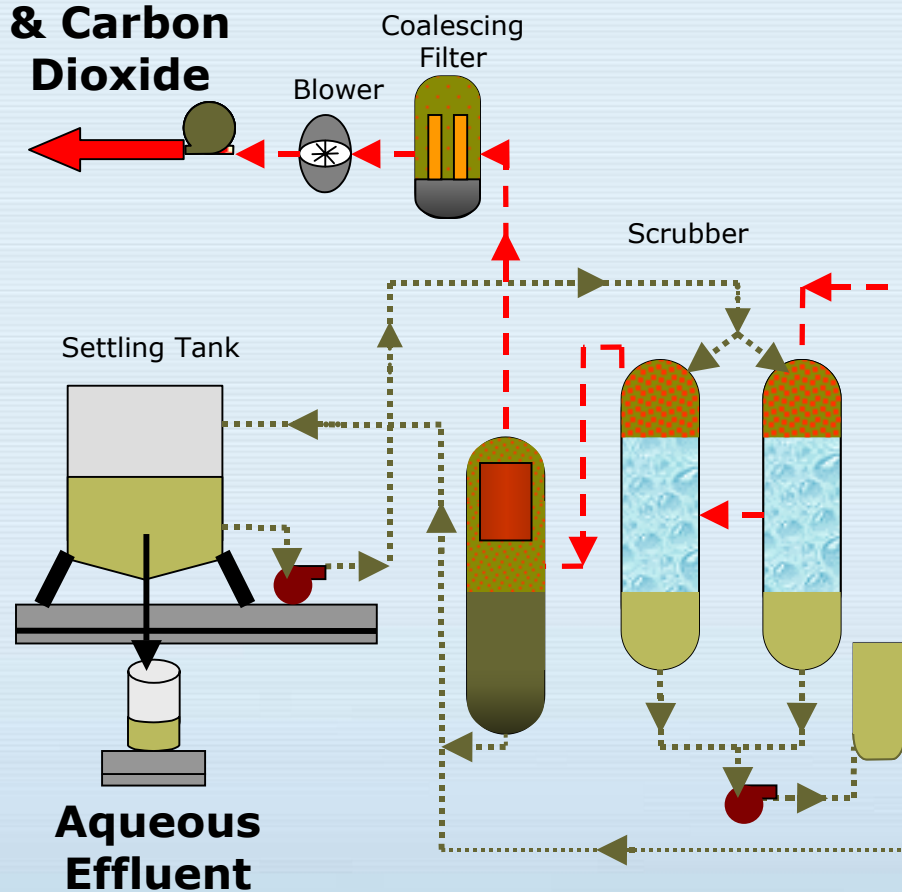




NREL

# TCPDU - Reformer Installation

## Hydrogen & Carbon Dioxide





NREL

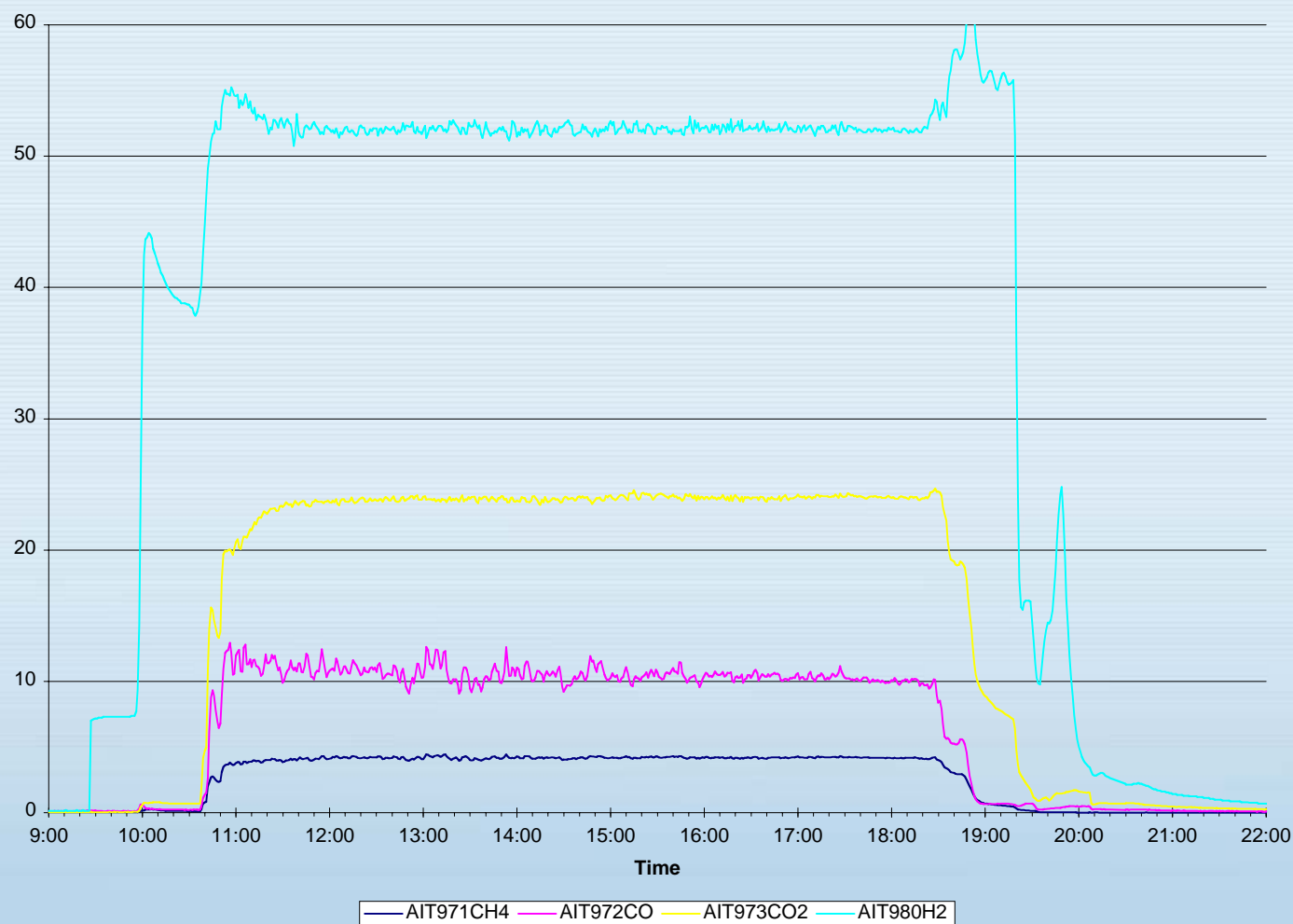
# Reformer at TCUF





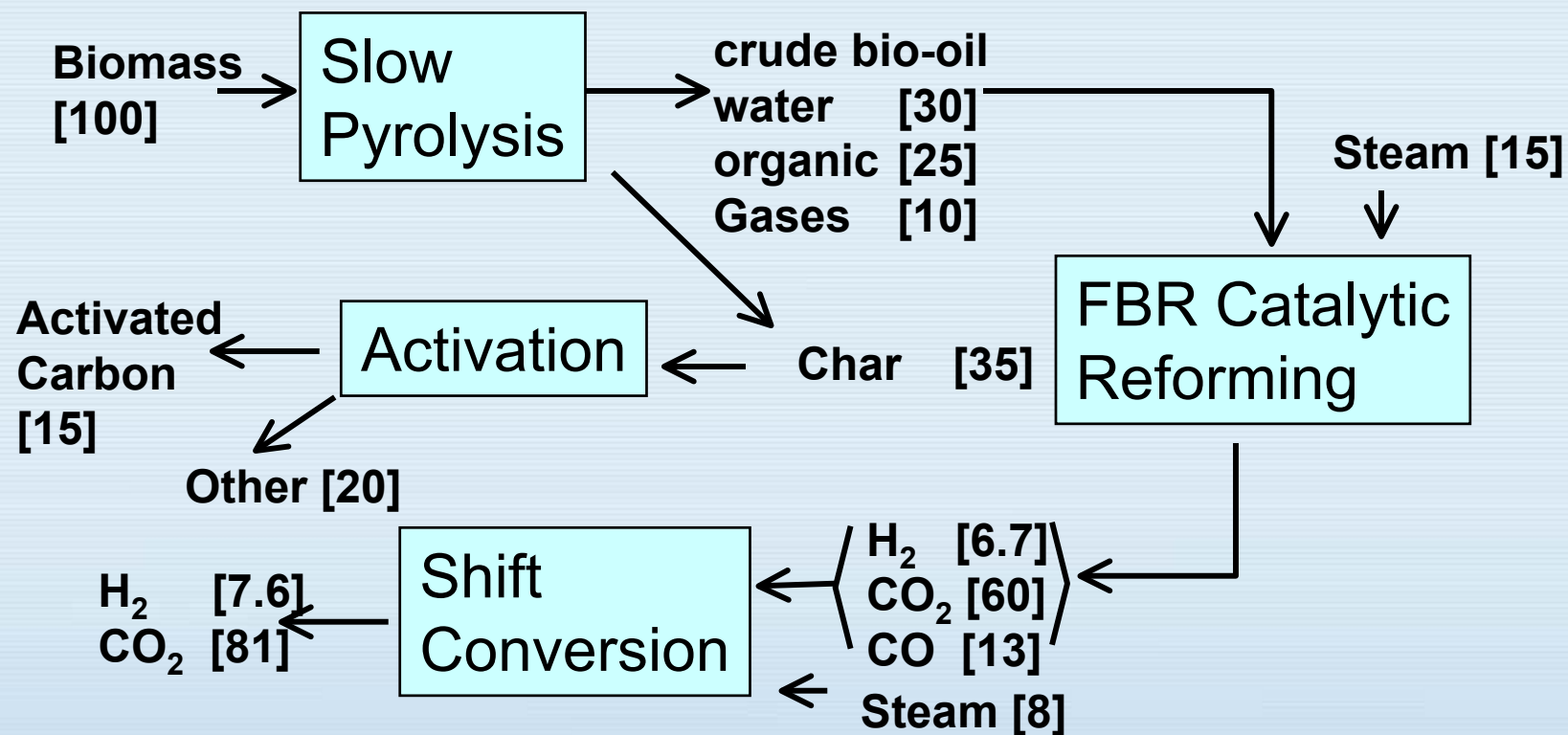
# TCPDU - Hydrogen Production

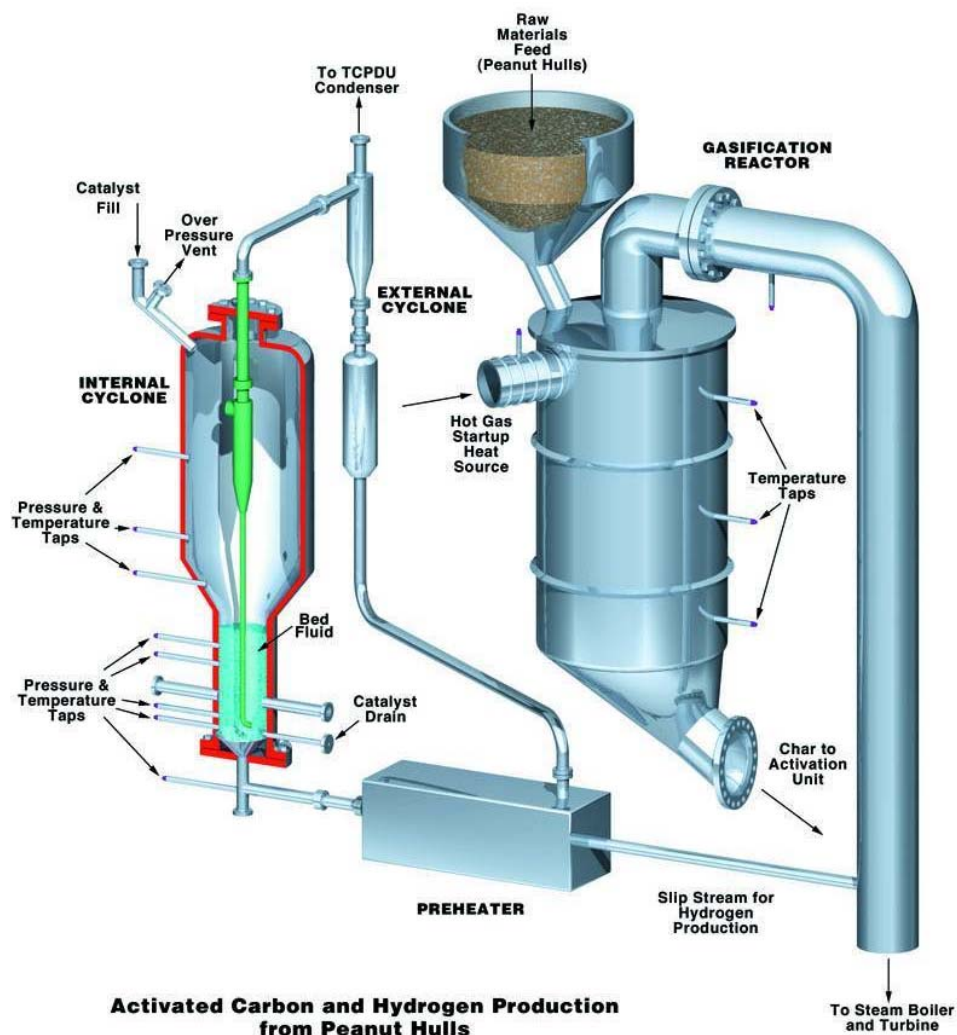
5-13-2002 Exit Gas Composition (peanut)





# Pyrolysis Mass Balance







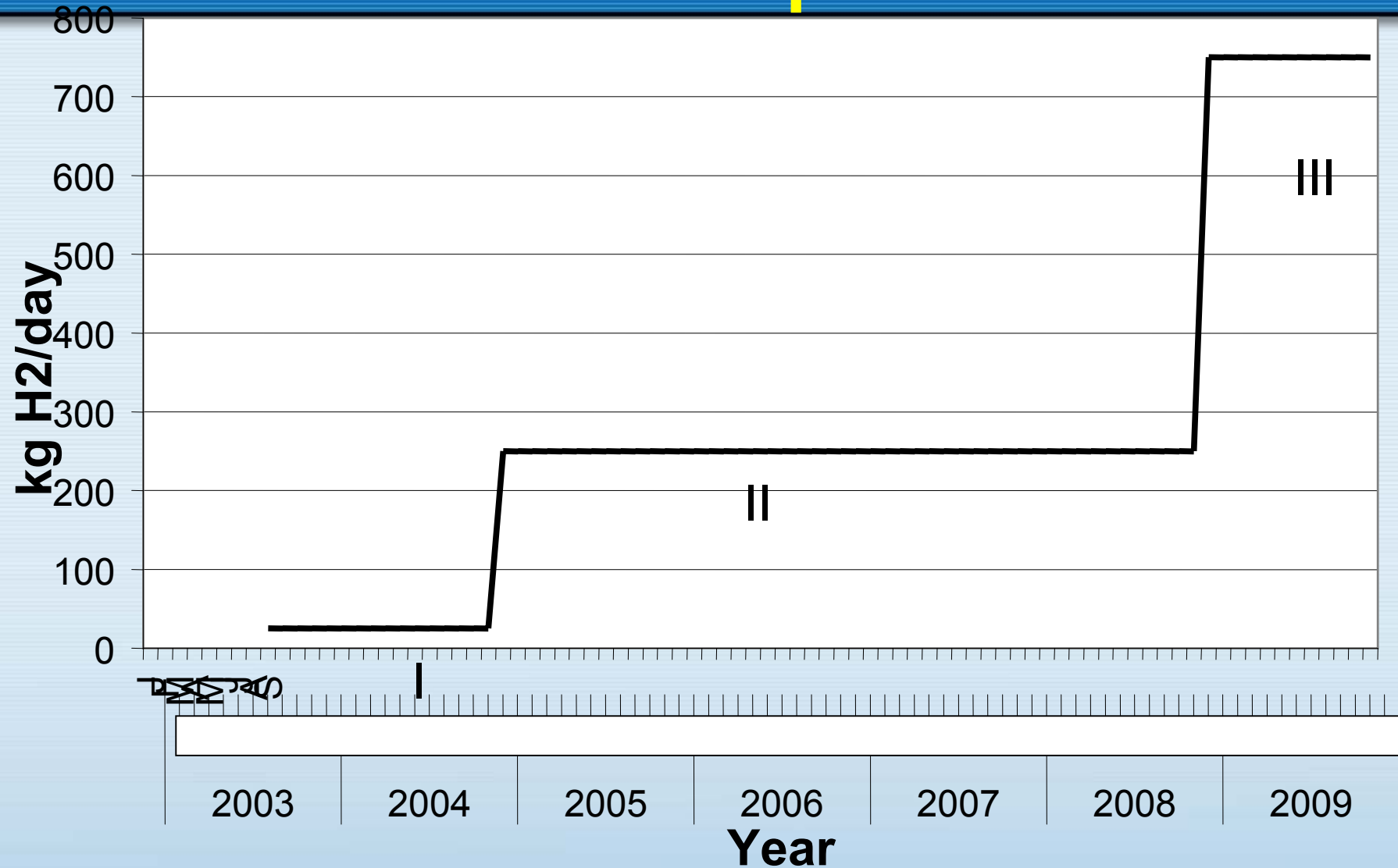
# Blakely Georgia Site



<b><u>Research &amp; Development</u></b>	<b><u>Demonstration</u></b>		
	Initial System Prototypes	Refined Prototypes	Commercial Prototypes
<ul style="list-style-type: none"> <li>• Research on component technologies</li> <li>• General assessment of market needs</li> <li>• Assess general magnitude of economics</li> </ul>	<ul style="list-style-type: none"> <li>• Integrate component technologies</li> <li>• Initial system prototype for debugging</li> </ul>	<ul style="list-style-type: none"> <li>• Ongoing development to reduce costs or for other needed improvements</li> <li>• “Technology” (systems) demonstrations</li> <li>• Some small-scale “commercial” demonstrations</li> </ul>	<ul style="list-style-type: none"> <li>• “Commercial” demonstration</li> <li>• Full size system in “commercial” operating environment</li> <li>• Communicate program results to early adopters/ selected niches</li> </ul>

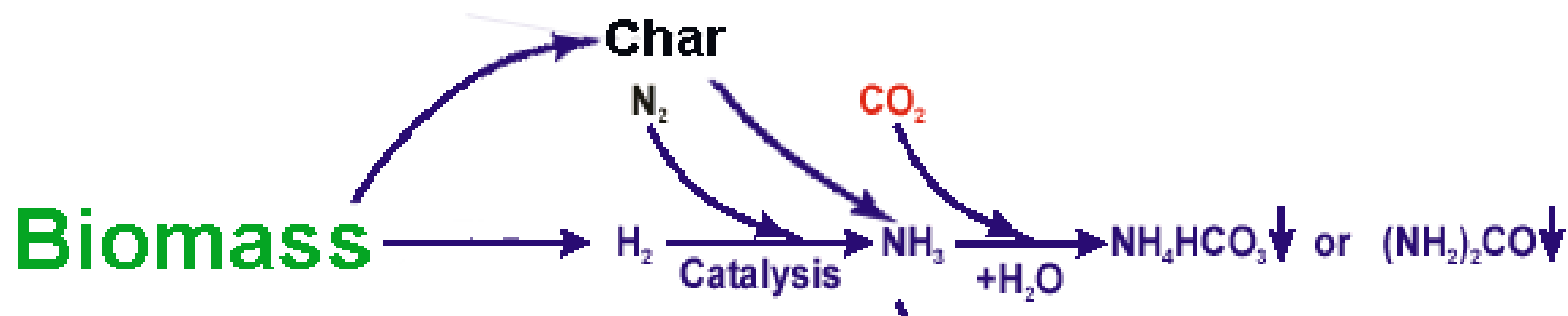


# Scale up Plan





# Biocarbon-Based Fertilizers



Mag = 422 X

20µm

EHT = 5.00 kV  
WD = 18 mm

Signal A = SE2  
Photo No. = 8426

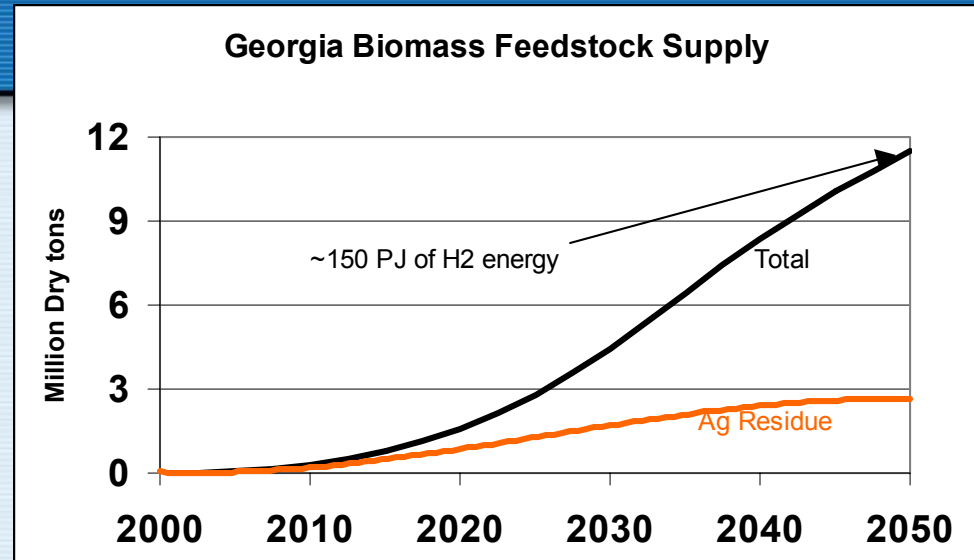
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## Impact assumptions

- Biomass target:  
15% of energy supply
- Assume 1/3 goes to H2  
= 5 exajoules for US
- Model on GA with  
population 8 million  
(50% rural, 50% urban)

Peanut shells are 10% of  
required Ag residues



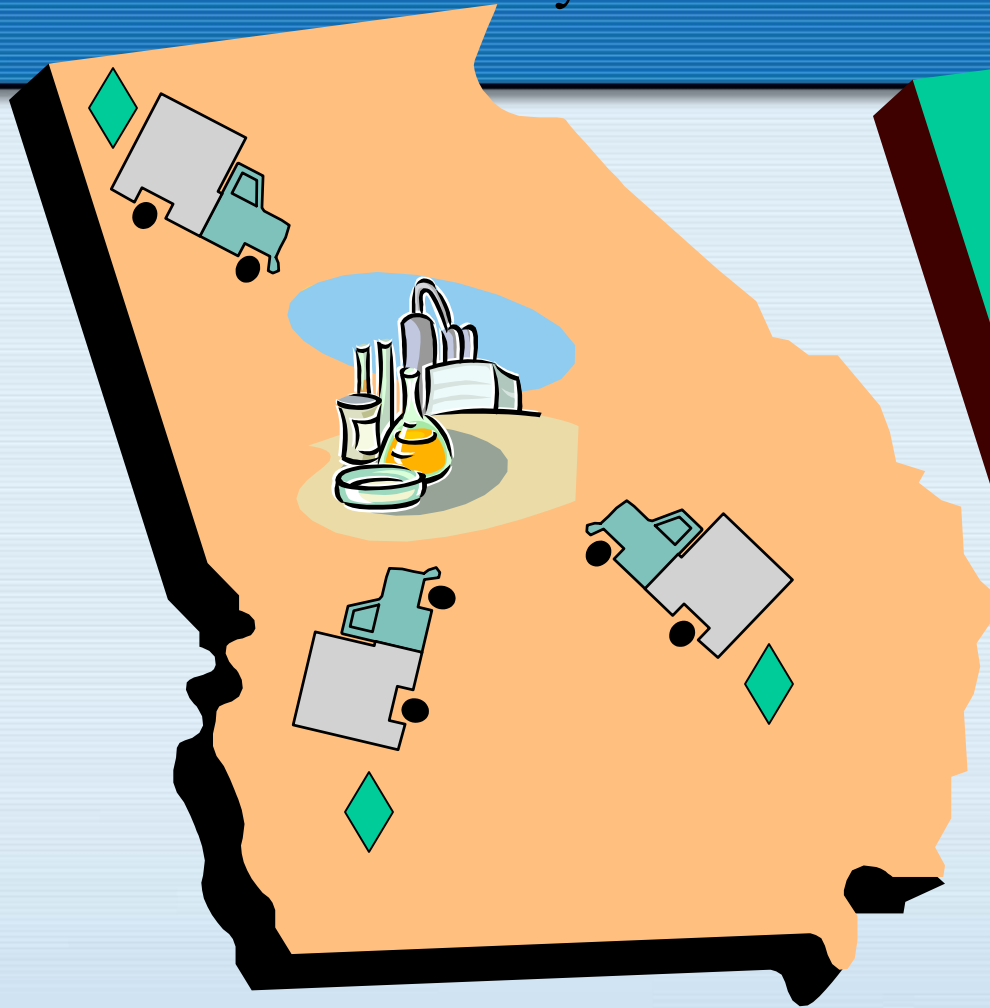
Assume equal supply:

- Ag Residues
- Forest residues
- Energy Crops
- Animal Manures
- MSW

~2 million tons/ year each

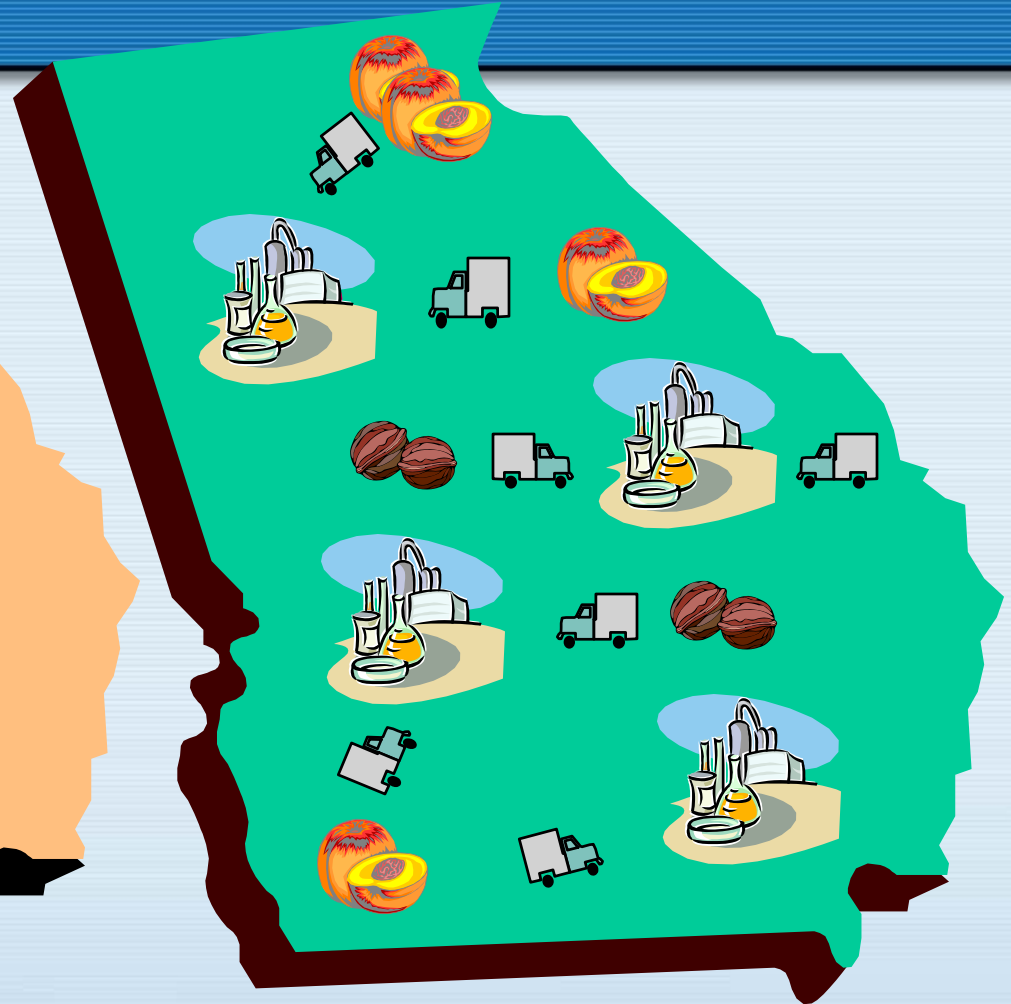
- Low % of total potential

## Traditional Facility Location



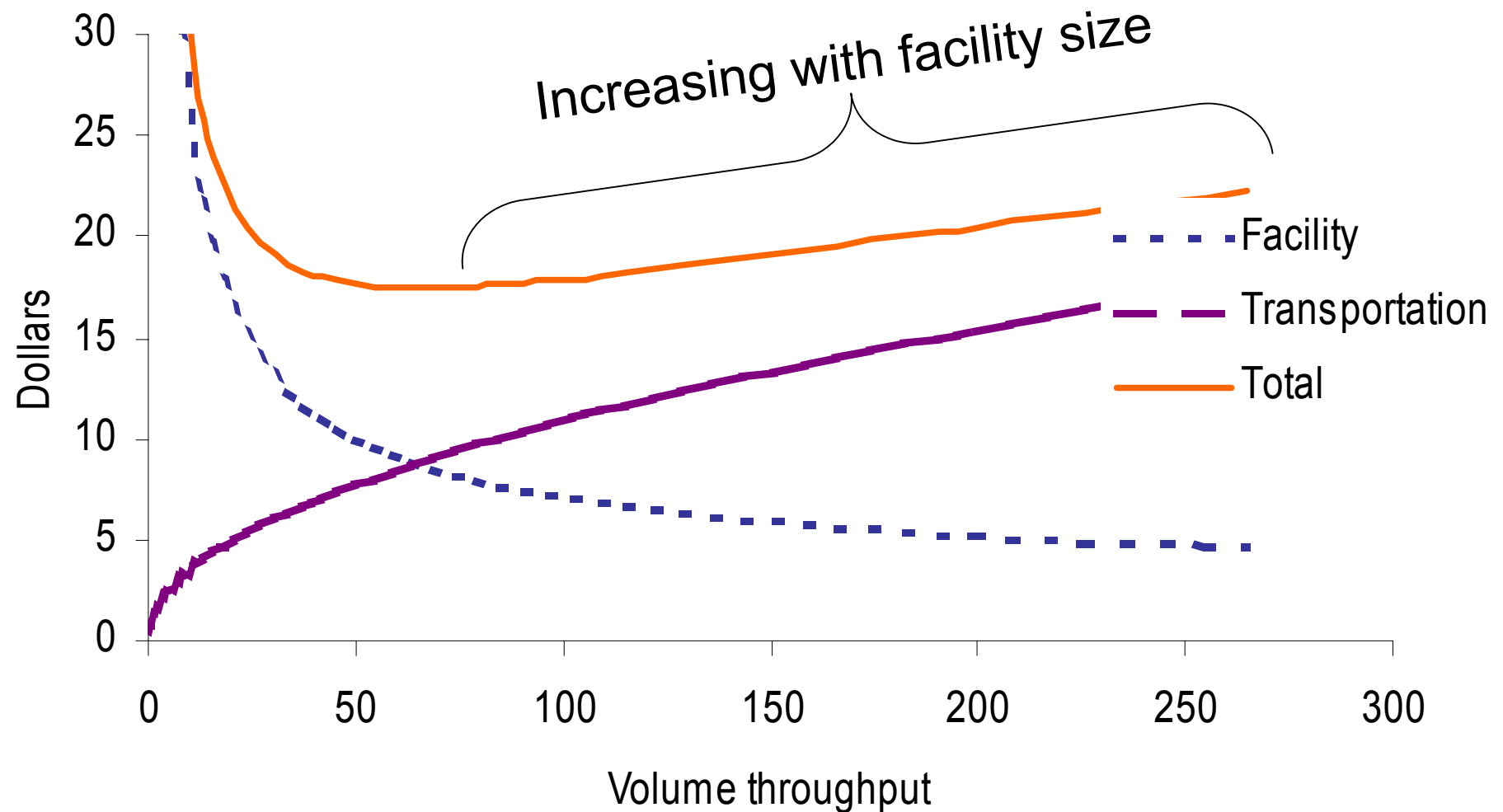
- Discrete Suppliers
- Economies of Scale

## Biomass Facility Location



- Continuously-distributed Supply
- Transportation Intensive
- Economies of Scope

## Qualitative Behavior of Total Costs for Processing Fixed Biomass Quantity





- Potential long term contribution of Bioenergy is 15%
- Biomass to Renewable Hydrogen is a promising near term approach with Co-product production
  - Pyrolysis with co-products \$7-9/MJ = Competitive!
- Shakedown of 7 kg/hour Catalytic Fluid Bed Reactor for over 100 hours of operation
- Work to begin at Georgia Site for 1000 hour run



# Acknowledgements

- **Support of the US DOE Hydrogen Fuel Cells and Infrastructure Technologies Program**
- **Coworkers at NREL and Georgia Team**
  - Clark Atlanta University
  - Scientific Carbons/ Eprida Inc
  - Enviro-Tech Enterprises Inc.
  - Georgia Institute of Technology